# FISH AND THE BARMAH-MILLEWA FOREST: HISTORY, STATUS AND MANAGEMENT CHALLENGES

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KING, A.J., 2005. Fish and the Barmah-Millewa Forest: History, status and management challenges. *Proceedings of the Royal Society of Victoria* 117(1):117-125. ISSN 0035-9211.

The Barmah-Millewa Forest is a large river red gum forest on the Murray River floodplain, well known for its ecological significance, particularly for waterbird breeding. Historically, a wide variety of native fish were abundant in the region, and they were an important component of the diet of the local Aboriginals. The region also quickly became the focus of a large commercial fishing enterprise after European settlement. Media records of the day suggest that the weekly catch varied from one to six tonnes of fish, mainly Murray cod (*Maccullochella peelii peelii*). Catches of native fish soon began to decline, and combined with the later effects of other factors such as river regulation, native fish populations declined rapidly to present day levels. Today, whilst the Forest's fish fauna has been reduced in abundance and diversity and introduced species are common, the Forest remains an important area for native fish. This paper discusses historical accounts and the current status of fish fauna in the region, and highlights a number of the specific challenges pertaining to the sustainable management and rehabilitation of native fish populations in the region.

*Key words:* Murray River, carp, wetlands, inland commercial fishery

THE BARMAH-MILLEWA Forest occurs on the Murray River floodplain upstream of Echuca. Whilst the Forest is principally recognised for its extensive River Red Gum stand, it also contains a variety of permanent and ephemeral aquatic habitats suitable for fish, including swamps, rushlands, open lakes, billabongs, creeks and open grassland areas when inundated, and the channels of the Murray and Edward Rivers and Broken Creek. Although largely hidden from the human eye, fish are an integral component of river ecosystems, and are important in the Barmah-Millewa region for ecological, recreational and cultural reasons.

## HISTORICAL PERSPECTIVE

Early accounts of the Barmah-Millewa region suggest that native fish were both diverse and highly abundant. The explorer Charles Sturt travelling through the region in 1838, noted a group of Aborigines fishing with "astonishing success" (Sturt 1838 cited in Leslie 1995): "the perch, the Dangan a species of barbel and a small fish like the roach with glittering silvery scales". (Perch were most likely golden perch (*Macquaria ambigua*), Dangan most likely freshwater catfish (*Tandanus tandanus*) and glittering silvery scaled fish perhaps bony herring (*Nematalosa erebi*) or silver perch (*Bidyanus bidyanus*)). Fish were an important food source for Aborigines, with Curr (1965) reporting that "… the [Aborigines] loved fish, more especially the fat fish, The supply of their favourite food existed in such abundance, and was so easily procured…". The Aboriginal fishing parties used a variety of methods to capture the fish including spearing, netting, hooked lines, trapping and poisoning waterholes. Some methods were quite ingenious and required significant skill. For example, Aboriginals constructed weirs from closely spaced wooden stakes across channels, trapping fish moving back into the river on receding floodwaters in spring and summer. This method was often highly successful, and able to supply their camps with abundant food for weeks (Curr 1965; Hibbins 1991). They were also proficient in capturing fish using underwater spearing and trapping techniques. One such method involved placing a hand net over the entrance of a hollow log on the bottom of the river, and forcing large cod from the log using branches pushed from the other end (Robinson 1988 cited in Leslie 1995).

These bountiful resources that were such an important food source and cultural activity for local Aboriginals were soon exploited by European settlers. In 1859, Joseph Waldo Rice (Rice's Weir on Broken Creek is named in his honour) established what was probably the first commercial inland fishing enterprise in Australia, largely centered at Moira Lake (Leslie 1995). The Lake Moira Fishing Company or Murray River Fishing Company (as it was later known) supplied fish to markets principally in Bendigo and Melbourne. The company employed ten (white) men full time, but also exploited the fishing skills of a number of Aboriginal men, who were paid with alcohol in-lieu of wages (Hibbins 1991; Leslie 1995). In 1869, the *Illustrated Australian News* (22 March 1869) reported that the weekly catch varied between one and six tonnes, and averaged three tonnes. Even out of season, half a tonne of fish was reputedly transported weekly to Melbourne markets (Priestley 1965). Leslie (1995) suggested that this average would have equated to around 160 tonnes of fish per year (or 32,000 individuals weighing an average 5kg) being removed from the lakes and rivers of the region. In 1883, the first official records from Moama show that around 150 tonnes of fish per year were transported to Melbourne markets. However this is still likely to be an underestimate of the total catch for the region, as it does not include fish transported directly to Echuca or fish sold locally, suggesting that the total catch delivered to Victorian markets from Echuca regularly exceeded 150 tonnes annually (Leslie 1995).

Catches were at their greatest during the spawning season, when fish were heavily targeted in the lakes and often sent to market in full roe. The Company was repeatedly criticised in the media for destroying "millions" of fish from Moira Lake (Leslie 1995). Until the 1860s, most fishing was centered on Moira Lake, with catches dominated by Murray cod (*Maccullochella peelii peelii*), but also included "bream, perch and carp" (*Illustrated Australian News*, 22 March 1869). (Bream were most likely silver perch, perch probably golden perch, and carp most likely goldfish (*Carassius auratus*) not common carp (*Cyprinus carpio*) as the latter was not recorded in the region until the late 1970s (Koehn et al. 2000)). However, by the 1890s the total catch taken to market had declined significantly to around only 35 tonnes per year, and was dominated by golden perch (Leslie 1995).

Legal commercial harvesting was not the only fishing operation affecting fish populations of the Barmah-Millewa region during this time. The region also supported Aboriginal subsistence fishing, and a large number of non-professional fisherman regularly fished the lakes and rivers of the region, using a variety of trapping and netting methods (Leslie 1995). In 1895, John Chanter, then Member for Murray in Victoria, described the scene on the Victorian side of the lakes as "just one mass of nets that are termed gill nets, and it is absolutely impossible for the fish to get out of the lakes into the river no matter how small or large the fish may be" (Chanter 1895, cited in Leslie 1995).

During the same time as commercial fishing operations were at their peak, paddlesteamer traffic on the Murray River in the region increased dramatically and fish habitat in the river subsequently suffered. When Europeans first came to the region, the Murray River was full of trees (or snags) that had fallen into the river over centuries (Hibbins 1991). To enable this new form of transport to navigate the waters safely, the snags were cleared from the water in their thousands. Early snagging attempts only cut the snags above the water line, but operations soon became more efficient with dedicated snagging boats removing the snags by winch and pulley. In 1864, a lone snagging crew consisting of a snag boat, two punts and bullock teams, dragged 962 snags from between Tocumwal and Wahgunyah and cleared over 500 overhanging trees on the edge of the river (Priestley 1965). Today, we know that native fish, such as the cods and perches, are highly reliant on snags as habitat in rivers (see Crook and Robertson 1999). The removal of such large numbers of snags throughout the region is likely to have had a profound impact on native fish populations. Whilst the removal of snags from rivers is now strictly controlled, the Murray River and its fish still suffer from the effects of the removal of such large numbers of snags.

## THE DECLINE IN NATIVE FISH POPULATIONS AND CURRENT STATUS

Concern over the decline in native fish numbers in the Barmah-Millewa region were reported as early as the mid 1860s (Leslie 1995), and more broadly throughout inland NSW by the 1880s (Rowland 1989). In 1892, John Manton, a Fisheries Inspector and Forest Ranger of the region, reported to the Fisheries Commissioners that:

> "For some years past the dearth of all kinds of fish has been great in the river Murray, owing to the vandalic and ill-controlled system of net-fishing … fishing by bag and gill nets is rapidly

> depopulating the fish in the river ... All the way up the river [from Echuca to the lakes] we saw signs of net fishing in every bend. ... The lakes covering so much low country they form the natural habitat of the fish, and when the water recedes from the land they naturally fall with it into the natural running channels, which is the Murray River. The lakes have about a hundred exits into that river past mud islands, bulrush swamps, gum-tree islands, sandbanks and water races, the very ponds for fish of six varieties. The lakes are the spawning grounds, and the young fish follow the old fish in shoals, through the said outlets. We patrolled these outlets ... and came across bag and gill nets across every outlet visited by us, and in the center of the lakes where the rushes and flotsam were thickest were more nets and fish boxes, securely and skillfully fixed. ... If such destruction is permitted to go on like that upon Lake Moira – and it is only one place on the Murray – the fish supply of the people will be ruined. Let it be protected at once." (*Echuca and Moama Border Post*, 4 January 1893, in Report of the Commissioners of Fisheries for NSW for 1892, cited in Leslie 1995).

Rowland (1989) suggested that overfishing by both commercial and recreational fishing caused the decline in the Murray River cod fishery until at least the 1930s. By the 1930s large-scale commercial harvesting operations were becoming uneconomical and people living along the inland rivers suggested that fish were much more difficult to catch (Dakin and Kesteven 1938). Further sharp declines in total catches of most native fish then occurred to today's current levels (Rowland 1989; Reid et al. 1997). As early as 1938, declining fish stocks and river regulation were being linked, especially in rivers such as the Murray and Murrumbidgee (Dakin and Kesteven 1938). This more recent decline is likely to be principally due to the effects of river regulation by decreasing spawning and recruitment success, reducing the availability of habitat both instream and floodplain and restricting movements (see Cadwallader 1978; Rowland 1989; Koehn 2002). rather than overfishing.

J.O. Langtry conducted ecological surveys along the Murray River in 1949 and 1950, and interviewed local game inspectors of the Barmah district. Before the completion of the Hume dam in 1936, the game inspector suggested that "fish were relatively plentiful, cod being very common ... Fishing was very intensive and often illegal, the lakes being fished with mesh nets and seine nets. ... Fish of all species were taken in abundance." However, after the construction of the dam "fishing declined noticeably", and "no Murray cod weighing less than about 2 lb (0.9 kg) have been taken ... by any method during the last 5-6 years", while tench, carp [most likely goldfish] and redfin, "after completely disappearing between 1943 and 1948, are now returning" (Cadwallader 1977). The inspectors also suggested that since construction of the dam, sedimentation has increased, aided by desnagging activities in the channels, resulting in reduced water depth and the transparency of the water, potentially smothering fish eggs and reducing their survival (Cadwallader 1977). Langtry also conducted surveys during this time in the Barmah lakes and recorded a number of

| Name as recorded by Langtry | Current common name |
|---|---|
| Murray cod | Murray cod |
| trout cod | trout cod |
| Macquarie perch | Macquarie perch |
| callop | golden perch |
| silver perch | silver perch |
| pigmy perch (*Nannoperca*) | southern pygmy perch |
| sunfish (*Melanotaenia nigrans*) | crimson-spotted rainbowfish |
| northern blackfish (*Gadopsis marmoratus*) | river blackfish |
| smelt (*Retropinna semoni*) | Australian smelt |
| catfish (*Tandanus tandanus*) | freshwater catfish |
| *Galaxias* spp. | Murray jollytail |
| redfin | Redfin |
| carp | Goldfish |
| tench | Tench |
| brown trout | brown trout |

*Table 1.* Fish species recorded by J.O. Langtry in 1949/50 surveys conducted in Barmah Lakes (Cadwallader 1977).

| Common name | Scientific name | Last Record | Relative Abundance | Conservation status NSW | Vic | National |
|---|---|---|---|---|---|---|
| **Native species** | | | | | | |
| Murray cod | *Maccullochella peelii peelii* | Recent | Common | | E | V |
| trout cod | *Maccullochella macquariensis* | Recent | Present | E | CE | E |
| golden perch | *Macquaria ambigua* | Recent | Common | | | |
| silver perch | *Bidyanus bidyanus* | Recent | Common | V | CE | |
| freshwater catfish | *Tandanus tandanus* | Recent | Rare | | E | |
| bony herring | *Nematalosa erebi* | Recent | Present | | | |
| river blackfish | *Gadopsis marmoratus* | Recent | Rare | | | |
| short-headed lamprey | *Mordacia mordax* | Recent | Rare | | | |
| Macquarie perch | *Macquaria australasica* | 1940s | Probably locally extinct | V | E | E |
| crimson-spotted rainbowfish | *Melanotaenia fluviatilis* | Recent | Rare | | DD | |
| Murray hardyhead | *Craterocephalus fluviatilis* | Recent | Rare | E | CE | V |
| unspecked hardyhead | *Craterocephalus stercusmuscarum fulvus* | Recent | Common | | DD | |
| Australian smelt | *Retropinna semoni* | Recent | Common | | | |
| carp gudgeons | *Hypseleotris sp.* | Recent | Common | | | |
| flathead gudgeon | *Philypnodon grandiceps* | Recent | Common | | | |
| southern pygmy perch | *Nannoperca australis* | Recent | Rare | V | | |
| southern purple-spotted gudgeon | *Mogurnda adspersa* | No record, likely to occur | Probably locally extinct | EP | RE | |
| Murray jollytail | *Galaxias rostratus* | No record, likely to occur | Rare | | | |
| climbing galaxias # | *Galaxias brevipinnis* | Recent | Rare | | | |
| **Introduced species** | | | | | | |
| common carp | *Cyprinus carpio* | Recent | Abundant | | | |
| goldfish | *Carasius auratus* | Recent | Common | | | |
| oriental weatherloach | *Misgurnus anguillicaudatus* | Recent | Common | | | |
| redfin perch | *Perca fluviatilis* | Recent | Common | | | |
| gambusia | *Gambusia holbrooki* | Recent | Abundant | | | |
| brown trout | *Salmo trutta* | Recent | Rare | | | |
| rainbow trout | *Oncorhynchus mykiss* | Recent | Rare | | | |
| tench | *Tinca tinca* | Recent | Rare | | | |

# Climbing galaxias were recorded in Barmah Forest in 1991 by McKinnon (1997), and is thought to be a translocated native species from coastal streams, having probably emigrated via water transfers from the Snowy Mountain Hydro-electric system (Waters *et al.* 2002).

*Table 2.* Status of fish of the Barmah-Millewa Forest region. Last record and relative abundance obtained from recent surveys, historical information in text or probable distribution. Conservation status as listed under *NSW Fisheries Management Act 1994*, *Flora and Fauna Guarantee Act* and conservation status DSE (2003), and *Environment Protection and Biodiversity Conservation Act 1999*. DD = data deficient, V= vulnerable, EP = endangered population, E = endangered, CE = critically endangered, RE = regionally extinct.

native species that are now either rarely caught or are listed as threatened species (see Tables 1 & 2).

Today, the Barmah-Millewa region of the Murray River no longer supports a native commercial fishery and recreational fishing opportunities have also declined. Indeed, native fish populations throughout the Murray-Darling Basin have undergone severe declines, with estimates suggesting that fish numbers in the Basin's rivers may be at 10% of their pre-European levels (MDBC 2003). Ten of the 18 native species recorded (or likely) from the Forest are currently listed under either State or Commonwealth threatened species legislation, and the fish of the region are also included in the listings of endangered ecological communities for both Victoria and NSW. Although the fish fauna has undoubtedly been significantly reduced in diversity and abundance since early European settlement, a large diversity of native species still utilise the Forest (McKinnon 1997; Stuart and Jones 2002; Jones and Stuart 2004; King unpublished data) and the region is still popular with recreational anglers, particularly those targeting Murray cod. Extensive surveys conducted in Barmah Forest in the early 1990s failed to record a number of species that were expected to be found, including freshwater catfish (*Tandanus tandanus*), crimson-spotted rainbowfish (*Melanotaenia fluviatilis*), flatheaded galaxias (*Galaxias rostratus*), southern pygmy perch (*Nannoperca australis*), hardyhead (*Craterocephalus spp.*) and Macquarie perch (*Macquaria australasica*) (McKinnon 1997). However, recent surveys have now recorded isolated populations of rainbowfish and pygmy perch, and unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*), which are commonly collected from a number of sites within the Forest (Alison King and Matthew Jones, Arthur Rylah Institute unpublished data). Additionally trout cod (*Maccullochella macquariensis*) and flathead gudgeon (*Philypnodon grandiceps*) that were only collected in small numbers by McKinnon (1997), are now commonly collected in the Forest waterways (Alison King and Matthew Jones, Arthur Rylah Institute unpublished data). Murray cod, golden perch and silver perch are also common throughout the region.

## CHALLENGES FOR FISH MANAGEMENT IN THE FOREST

### *River regulation, water management and environmental flows*

As a result of flow regulation of the Murray River, the natural flooding and drying cycles of the Forest have been significantly altered. Today, the Forest experiences a reduction in the frequency and duration of winter and spring floods and a slight increase in the frequency of small summer flood events (Bren et al. 1987). In an attempt to mitigate some of the effects of river regulation on the Forest, regulators have been installed to reduce the impact of unseasonal summer watering, and an annual environmental water allocation (EWA) of 150 GL per year has also been implemented. Use of the EWA is not required each year, and the allocation is often accumulated for a number of years and used in bulk volumes, typically to extend the duration of natural flow events originating from the Ovens River catchment upstream. Barmah-Millewa Forest has been recognised as an icon site under the Murray-Darling Basin Commission's Living Murray initiative, and further environmental watering opportunities and management initiatives in future years are planned (MDBMC 2004).

Flooding is thought to provide a wide range of benefits to native fish including a potential cue for spawning and adult migration; inundated floodplains are potentially important nursery areas for young fish, and flooding also allows older fish to feed, disperse to new habitats and accumulate fat reserves (Humphries et al. 1999; Welcomme 2001; King et al. 2003). Whilst the existing Barmah-Millewa EWA has been operating for a number of years, little is known about how natural and managed flood events influence fish populations in the Forest. McKinnon (1997) suggested that large spring flood events seemed to increase catch rates and also the diversity of native fish in some sections of Barmah Forest. A current project is examining the role of flow regimes on native and introduced fish spawning and recruitment throughout the various Forest habitat types. Whilst the project has only been sampling for the past two years, with few floodplain inundation events occurring, a number of rare and recreationally important species have been shown to be both spawning and recruiting within the Forest system (King et al. 2005; King unpublished data). The project should aid in improving environmental watering strategies for native fish populations in Barmah-Millewa and other floodplain wetlands in the Murray Valley.

The reduction in frequency, duration and magnitude of flooding in the Forest is likely to have also altered the diversity of habitats within the Forest available to fish. Recent surveys of small fish species have suggested that some species, such as crimson-spotted rainbowfish and southern pygmy perch, are highly restricted and occur in only a few isolated waterbodies throughout the Forest (King unpublished data). Flooding and subsequent floodplain connectivity provides the only mechanism whereby individuals from these isolated populations can disperse into new waterbodies. Fish are likely to use the Forest for many functions and the maintenance of a diverse mosaic of habitat types and connectivity between them is a key issue for future water and native fish management of the Forest.

*Operation of floodplain regulators*

Numerous flow regulating structures of various designs have been constructed across creeks and floodways along the Murray and Edward river channels in the Forest. The regulators are used to prevent unseasonal flooding of the Forest during the artificially high summer irrigation flows. During major flood events the regulators are fully open with water moving widely across the Forest floodplain. The regulators can also be manipulated to direct lower flood levels to specific water management areas, inundating particular wetlands or areas of forest. Whilst the regulators are primarily operated to improve the ecological health and access into the Forest, they can act as major obstructions for fish movement between the River and its floodplain, and the rapid closing of regulator gates can isolate large numbers of native and introduced fish. Langtry first recorded the effects of the regulators on fish movements:

> "now, in the summer, when the flow from the Murray falls below the level of this dam [the Gulf regulator], fish cannot move upstream into the Murray and hundreds of fish from 3 to 5 inches (76 – 127 mm) long are trapped below the dam. Inspector Arantz has taken approximately 3000 catfish and Macquarie perch from below "Gulf" anabranch dam." (Cadwallader 1977).

Jones and Stuart (2004) pumped water out of the pools downstream of the Gulf regulators in May 2003, and found 196 native and 4599 introduced fish trapped. Many of these fish displayed signs of stress including large numbers of ulcers, lesions and lernaea, and therefore it was likely that many of the fish trapped behind the regulators would have died (Jones and Stuart 2004). This, together with other recent research, clearly demonstrates that the current operation of regulators is having detrimental impacts on native fish movements in the region (Matthew Jones, pers. comm.). Further research is focused on determining the environmental cues that trigger fish to move laterally between the River and floodplain creeks, and investigating the effects of altering gate operations on fish movement and entrapment (Matthew Jones, pers. comm.). Future management strategies to mitigate the negative impacts of regulators on fish could include slowing the rate of dewatering and closure of regulator gates to increase the chance of fish moving into refuge areas, installing fishways on regulators on major creek lines, or the removal of some structures.

*Management of introduced species, particularly carp*

Eight introduced fish species are found in the Forest, with five; common carp, goldfish, redfin (*Perca fluviatilis*), weatherloach (*Misgurnus anguillicaudatus*) and gambusia (*Gambusia holbrooki*) recorded in large numbers in recent surveys (McKinnon 1997; Stuart and Jones 2002; Jones and Stuart 2004; King unpublished data). Oriental weatherloach have rapidly increased in number and spread throughout the Forest since the early 1990s, when McKinnon (1997) recorded only 2 individuals, to the present day where they are very common in a range of habitat types (Stuart and Jones 2002; Jones and Stuart 2004; King unpublished data).

Whilst the other introduced species are also likely to have impacts on native fish of the region, most attention is focused on the ecological effects of carp. Electrofishing surveys conducted between 1999 and 2001 found carp to be the most abundant large species collected in the River and floodplain habitats, comprising 86% of the biomass (Stuart and Jones 2002). Whilst carp spawning and recruitment is still successful even during low water years in Barmah-Millewa Forest (King unpublished data), inundated floodplain habitats of the Forest are major sources of young-of-year carp for the mid-Murray region (Stuart and Jones 2002; Crook 2004). Stuart and Jones (2002) suggested that the mouths of both Moira and Barmah lakes appear to be critical floodplain entry and exit points for carp in the Murray River, and any management actions employed (eg. harvesting) should target these key sites. Indeed, in recent years commercial harvesting of adult carp has occurred in Moira Lake, with catches varying from a peak of 76 tonnes (average weight 3kg) in 2001, to less than 20 tonnes in more recent years (Keith Bell, K & C Fisheries, pers. comm.). Management of introduced fish species, particularly carp, is a difficult and multi-jurisdictional issue that should be undertaken using pest management principles using a combination of control options such as commercial harvesting at key sites, trapping within fishways, and if possible, water level manipulations and trapping to reduce recruitment and opportunities for dispersal between wetlands (Koehn et al. 2000).

*Minimising the risks of blackwater events that may lead to fish kills*

Blackwater events during flooding are a natural process resulting from increased concentrations of dissolved organic matter which turn the water a yellow-brown, tannin colour. Blackwater is typically oxygen deficient from an increase in the biological oxygen demand by microbial organisms processing the organic matter. The combination of hypoxia (low dissolved oxygen levels) and elevated concentrations of polyphenolic compounds in the water can have detrimental effects on fish, including avoidance behaviour and even fish kills (Gehrke et al. 1993; McKinnon 1995; McKinnon and Shepheard 1995). Due to river regulation, the Barmah-Millewa Forest now experiences fewer large floods, resulting in a greater accumulation of leaf litter on the floodplain, and also an increase in low level floods during the warmer summer months. There are several reports of blackwater events associated with summer flooding in the Forest (McKinnon and Shepheard 1995; McKinnon 1997; Stuart and Jones 2002).

During a major spring-summer flood in 2000, dissolved oxygen levels were reported to be as low as 0.5 mg $L^{-1}$ on the Barmah floodplain (Ivor Stuart, Arthur Rylah Institute, pers. comm.). This event triggered a mass emergence of Murray crayfish (*Euastacus armatus*) from the river and floodplain, where hundreds of crayfish were seen climbing onto the river bank and up snags to escape the de-oxygenated water. McKinnon (1995) reported a similar mass emergence of crayfish in the Murray River downstream of the Barmah-Millewa Forest during the recession of the December 1992 - January 1993 floods. In October 1993, a large flood that inundated cropping land for a long period contributed to extremely low oxygen levels in Broken Creek, downstream of Nathalia, resulting in a fish kill involving mainly Murray cod, redfin and shrimp (McKinnon and Shepheard 1995). Unfortunately, Broken Creek suffered a much more severe fish kill in November 2002, when 179+ large adult Murray cod were found dead (King pers. obs.; Koehn in press). Whilst the exact cause of these deaths is still uncertain, low dissolved oxygen levels were involved, but were not caused by a blackwater event. The loss of such a large number of fish in the region is of major concern for conservation efforts for the species, especially considering that subsequent surveys of the reach have found that only a few individuals have returned (Steve Saddlier, unpublished data).

Whilst blackwater events are a natural occurrence, the impacts on aquatic fauna can be significant, and are certainly exacerbated by increased organic matter, reduced flushing rates and high temperatures, particularly if fish are restricted in their movements (by for example weirs, levees and regulators) and are unable to escape to alternative, more favourable habitats. The recent blackwater events within the forest itself have not caused any observed fish kills, and this is likely to be due to the ability of fish to escape from the Forest into the river. However, this suggests that any future management plans to restrict water movement in the Forest using additional levees or other barriers to fish movement should be viewed with caution. Future research on the effects of forest blackwater events on fish, particularly their behavioural responses and lethal levels is required to address this issue.

Recent modeling scenarios of the interaction of flooding and blackwater events in river red gum forests suggests that pooled, prolonged flooding of lowland forests increases the risks of blackwater events, and that flooding in the summer months reduces the amount of time taken for floodwaters to become anoxic (Howitt et al. 2004). This is an extremely important aspect for water management in the Forest, and suggests that care must be taken, particularly for warmer summer floods, to allow a significant amount of water exchange between the Forest waters and the river to minimise the risks of blackwater.

## CONCLUSION

The Barmah-Millewa Forest is widely recognised as a site of ecological significance. Much attention is focussed on some of the Forest's key ecological features, such as waterbird diversity and the dominant vegetation communities. However, whilst native fish have undoubtedly undergone major declines since early European settlement of the region, they are still a highly diverse and important component of the Forest's and River's ecology. Future management of the Forest needs to be able to better balance all attributes of the Forest's ecology, and strive to restore key ecological processes such as recruitment, movement and food production for native fish populations, while disadvantaging introduced species. However, the Forest is a highly complex ecosystem with a mosaic of different habitat types each with various water requirements, and balancing all of the

Forest's requirements, with only the limited environmental water available, will not be easy. With this in mind, future management should consider exploring various water management options, and testing and evaluating these using an adaptive management framework. Whilst we are now recognising the importance of native fish populations in this region, we still have much to learn about the ecology of fish and their use of the Forest.

## ACKNOWLEDGEMENTS

I particularly acknowledge the significant amount of historical research undertaken by David Leslie on fishing in the Barmah-Millewa region, from where much of the information reported here was cited. Thank you also to the members of the Barmah-Millewa Forum for sharing their many stories and love of the Forest and its fish fauna. Ivor Stuart, David Crook and John Koehn provided helpful comments on drafts of the manuscript.

## REFERENCES

Bren, L.J., O'Neill, I.C. & Gibbs, N.L., 1987. Flooding in the Barmah Forest and its relation to flow in the Murray-Edward River system. *Australian Forestry Research* 17: 127-144.

Cadwallader, P.L., 1977. *J.O. Langtry's 1949-50 Murray River Investigations*. Ministry for Conservation Fisheries and Wildlife Division. Melbourne, Australia. 70 pp.

Cadwallader, P.L., 1978. Some causes of the decline in range and abundance of native fish in the Murray-Darling river system. *Proceedings of the Royal Society of Victoria* 90: 211-24.

Chanter, J.M., 1895. *Royal Commission on Fisheries. The Murray River*. Minutes of evidence given on 16/10/1895 at Sydney. Supplementary Report: 79-82. cited in Leslie 1995.

Crook, D.A., 2004. *Contribution of the Barmah-Millewa Floodplain Lakes to Carp Populations in the Mid-River Murray*. Final report to Barmah-Millewa Forum. Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg, Victoria, 33pp.

Crook, D.A. & Robertson, A.I., 1999. Relationships between riverine fish and woody debris: implications for lowland rivers. *Marine and Freshwater Research* 50: 941-53.

Curr, E.M., 1965. *Recollections of Squatting in Victoria: then Called the Port Phillip District from 1841 to 1851*, 2nd edn. Melbourne University Press.

Dakin, W.J. & Kesteven, G.L., 1938. The Murray cod. *State Fisheries Research Bulletin* 1: 1-18.

DSE (Department of Sustainability and Environment), 2003. *Advisory List of Threatened Vertebrate Fauna in Victoria – 2003*. Department of Sustainability and Environment, Victoria, East Melbourne.

Gehrke, P.C., Revell, M.B. & Philbey, A.W., 1993. Effects of river red gum, *Eucalyptus camaldulensis*, litter on golden perch, *Maequaria ambigua*. *Journal of Fish Biology* 43: 265-79.

Hibbins, G.M., 1991. *Barmah Chronicles*. Lynedoch Publications, Melbourne, 144 pp.

Howitt, J., Baldwin, D., Rees, G. & Williams, J., 2004. Modelling blackwater: predicting water quality during flooding of lowland river forests. In *Blackwater Model – A Computer Model to Predict Dissolved Oxygen and Dissolved Carbon Downstream of Barmah-Millewa Forest Following a Flood*. Murray-Darling Freshwater Research Centre, Albury, Australia, 22-46.

Humphries, P., King, A.J. & Koehn, J.D., 1999. Fish, flows and flood plains: links between freshwater fishes and their environment in the Murray-Darling River system, Australia. *Environmental Biology of Fishes* 56: 129-51.

Jones, M. & Stuart, I., 2004. *Impact of Flow Regulation Structures on Fish in the Barmah-Millewa Forest*. Freshwater Ecology, Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Melbourne, 69 pp.

King, A.J., Crook, D.A., Koster, W.M., Mahoney, J. & Tonkin, Z., 2005. Comparison of larval fish drift in the Lower Goulburn and mid-Murray Rivers. *Ecological Management and Restoration* 6(2): 136-138.

King, A.J., Humphries, P. & Lake, P.S., 2003. Fish recruitment on flood plains: The roles of patterns of flooding and life history strategies.

*Canadian Journal of Fisheries and Aquatic Sciences* 60: 773-786.

KOEHN, J.D., 2002. Fish of the Murray River. *Victorian Naturalist* 119(4): 152-159.

KOEHN, J.D., in press. The loss of valuable Murray cod in fish kills: a science and management perspective. In *Management of Murray Cod in the Murray-Darling Basin: workshop held in Canberra, 3-4 June 2004: Statement, recommendations and supporting papers*. M. Lintermans & B. Phillips, eds, Murray-Darling Basin Commission, Canberra.

KOEHN, J.D., BRUMLEY, A. & GEHRKE, P.C., 2000. *Managing the Impacts of Carp*. Australia, Bureau of Rural Sciences, Department of Agriculture, Fisheries and Forestry, Canberra, 249 pp.

LESLIE, D.J., 1995. *Moira Lake: A Case Study of the Deterioration of a River Murray Natural Resource*. Unpublished Thesis (M.For.Sc.) University of Melbourne, 188 pp.

MCKINNON, L.J., 1995. Emersion of Murray crayfish, *Euastacus armatus* (Decapoda: Parastacidae), from the Murray River due to post flooding hypoxia. *Proceedings of the Royal Society of Victoria* 107(1): 31-38.

MCKINNON, L.J. 1997. *Monitoring of Fish Aspects of the Flooding of Barmah Forest*. Marine and Freshwater Resources Institute, Queenscliff, Australia, 184 pp.

MCKINNON, L.J. & SHEPHEARD, N., 1995. Factors contributing to a fish kill in Broken Creek. *Victorian Naturalist* 112(2): 93-99.

MDBC, 2003. *Native Fish Strategy for the Murray-Darling Basin 2003-2013*. Murray-Darling Basin Commission, Canberra, 50 pp.

MDBMC, 2004. The living Murray environmental works and measures program, November 2004. Murray-Darling Basin Ministerial Council, Canberra.

PRIESTLEY, S., 1965. *Echuca: A Centenary History*. The Jacaranda Press, 188 pp.

REID, D.D., HARRIS, J.H. & CHAPMAN, D.J., 1997. *NSW Inland Commercial Fishery Data Analysis*. NSW Fisheries, Sydney, Australia, 44 pp.

ROBINSON, G.A., 1988. *The Port Phillip Journals of George Augustus Robinson: 8 March–7 April 1842 and 18 March–29 April 1843*, edited by Ian D. Clark. Monash Publications in Geography 34 (cited in Leslie 1995).

ROWLAND, S.J., 1989. Aspects of the history and fishery of the Murray cod, *Maccullochella peeli* (Mitchell)(Percichthyidae). *Proceedings of the Linnean Society of New South Wales* 111(3): 201-3.

STUART, I. & JONES, M., 2002. *Ecology and Management of Common Carp in the Barmah-Millewa Forest*. Freshwater Ecology, Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Melbourne, Australia, 214 pp.

STURT, C., 1838. *Hand-written Journal for 1838*. State Library of Victoria (cited in Leslie 1995).

WATERS, J.M., SHIRLEY, M. & CLOSS, G.P., 2002. Hydroelectric development and translocation of *Galaxias brevipinnis*: a cloud at the end of the tunnel? *Canadian Journal of Fisheries and Aquatic Sciences* 59(1): 49-56.

WELCOMME, R.L., 2001. *Inland Fisheries Ecology and Management*. Fishing News Books, Blackwell Science Ltd, Oxford, 378 pp.